Gamma Ray Large Area Space Telescope (GLAST)

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Gamma Ray Astrophysics
Work Unit 0953

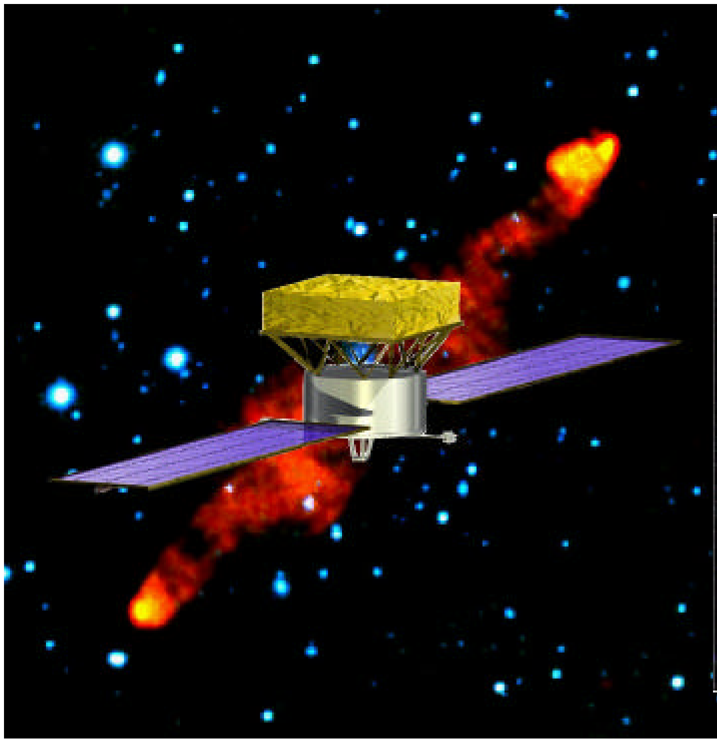
- GLAST Mission
- Organization, NRL Role
- Science Objectives
- Instrument Design
- Calorimeter Concept
- Calorimeter Development

The GLAST Mission

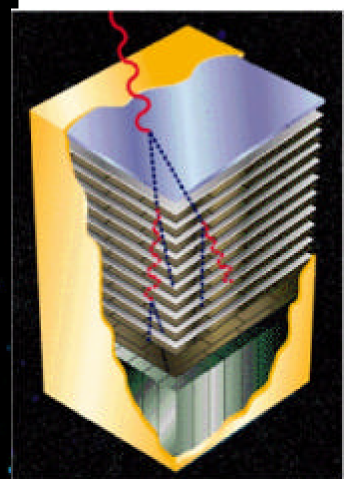
Gamma Ray Large Area Space Telescope

An International Space Mission under development by NASA and DOE for possible 2005 launch.

Mission Objective: The study of compact and extended cosmic sources of high-energy particles and radiation (10 MeV - 300 GeV) with a large area, wide field-of-view, imaging telescope



Primary Instrument: Pair-conversion telescope, using solid-state particle tracking technology, and CsI Imaging calorimeter



One of 25 GLAST Modules with tracker planes on top and CsI calorimeter below

- GLAST is a peer-reviewed mission concept, selected for study in March 1995 for possible flight in the next decade;
- It was endorsed as the priority gamma-ray mission by the NASA Gamma-Ray Astronomy Program Working Group
- NASA initiated a GLAST Advanced Technology Program in 1998
- GLAST is included in NASA's Space Science Enterprise Strategic Plan with 2002 new start and 2005 launch

Organization Chart
Instrument Technology Development Program

GLAST Facility Science Definition Team
Co-Chairs - N. Gehrels, GSFC
P. Michelson, Stanford

NASA
Goddard Space Flight Center
Project Formulation Manager - Code 740.2
M. DiJoseph

Collaboration of >120 scientists from 26 institutions

Instrument Development Steering Committee
Chair - N. Gehrels, GSFC

Stanford University
PI - P. Michelson, Phys. Dept & HEPL
Co-PI - E. Bloom, SLAC(DOE)

Development Manager - S. Williams, HEPL

Lead Development Engineers
Mechanical - B. Feerick, SLAC
Electrical - R. Williamson, HEPL

Indep. Review Panels

Instrument Development Steering Committee Members:
- Subsystem Managers
- N. Gehrels, GSFC
- W. Atwood, SU/UCSC
- G. Barbiellini, INFN, Italy
- E. Bloom, SU
- I. Grenier, CE Saclay, France
- T. Kamae, U. Tokyo, Japan
- P. Michelson, SU
- S. Ritz, GSFC
- H. Sadrozinski, UCSC
- K. Wood, NRL

1. Tracker
Manager - R. Johnson, UCSC
UCSC, SLAC, Japan, Italy

2. ACD
Manager - J. Ormes, GSFC
GSFC

3. Calorimeter
Manager - N. Johnson, NRL
NRL, GSFC, France, Italy

4. Data Acquisition
Manager - R. Williamson, SU
SU, NRL, GSFC

5. Software
Manager - T. Burnett, UW
UW, NRL, SU, SLAC, GSFC

NRL's Role in GLAST

NRL Gamma Ray Group leads the GLAST calorimeter development team.

Accomplishments:

- Demonstrated CsI/PIN calorimeter concepts in 1996 beam test at SLAC (ONR 6.1, NASA SR&T).
- Proposed and fabricated hodoscopic configuration and tested in 1997 beam test. Subsequently selected as baseline configuration. (ONR 6.1, NASA SR&T).
- Leading calorimeter ATD development of prototype GLAST tower (ONR 6.1, NASA ATD, SR&T)

Key Personnel:

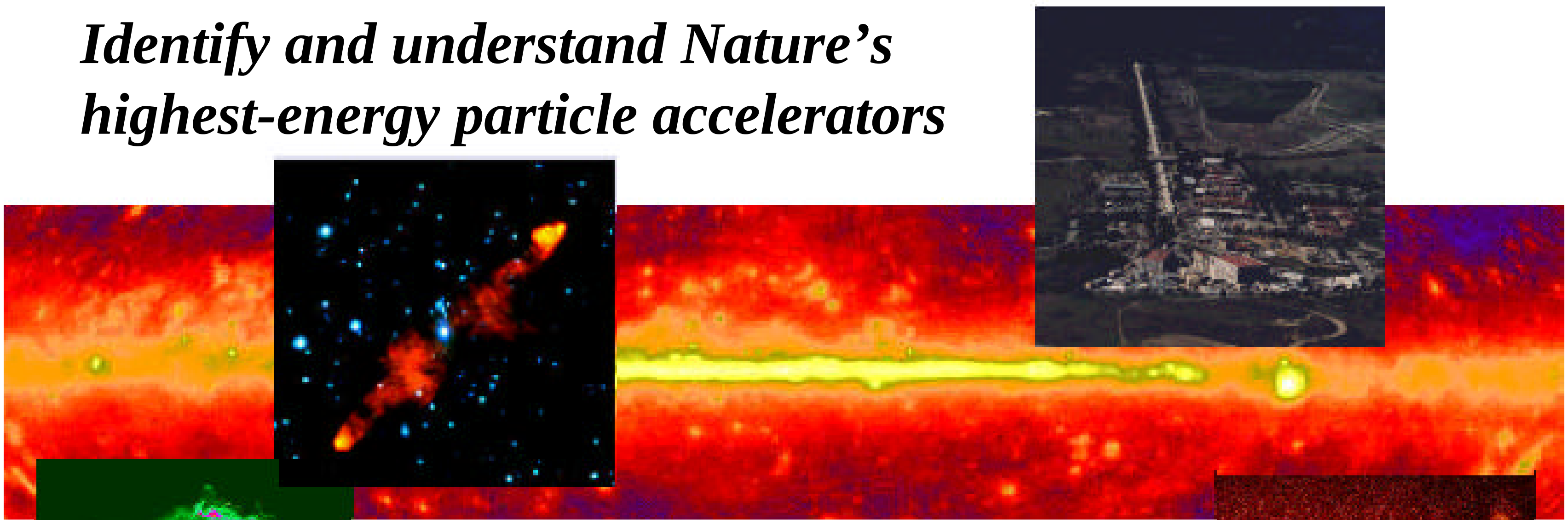
J. Eric Grove, W. Neil Johnson, Bernard Phlips (USRA)

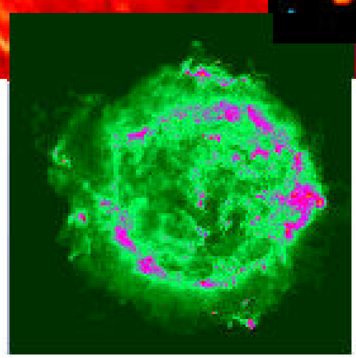
Collaborators (calorimeter):

NRL	Management, Mechanical & Electronics Design, Fab, I&T, Calibration
NASA/GSFC	Electronics (ASIC) Simulations
U. Texas	Simulations
France, Italy	Future development role

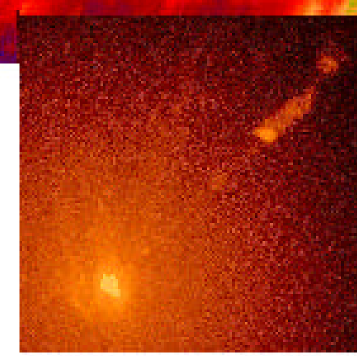
GLAST Science Objectives

Identify and understand Nature's highest-energy particle accelerators





- *active galactic nuclei*
- *pulsars*
- *black holes*
- *supernova remnants*
- *gamma ray bursts*



Use these sources to probe important physical parameters of the Galaxy and the Universe not readily measured with other observations.

The Science Potential of GLAST

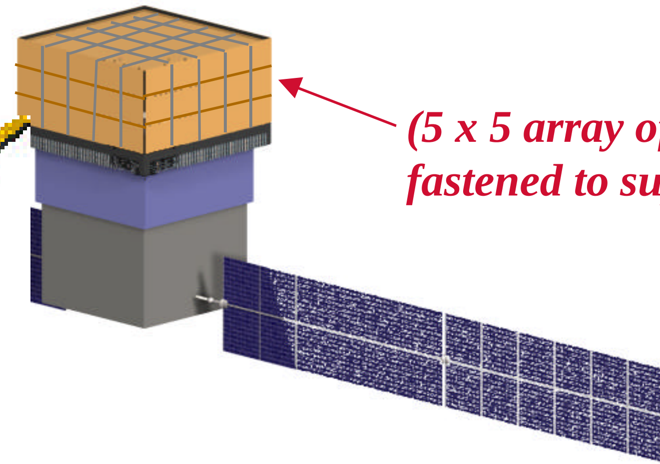
- GLAST will detect thousands of Active Galactic Nuclei (AGN)
  - EGRET has shown that Blazars can be most luminous in γ-rays
  - Explore the central engine and jet - particle content, acceleration mechanisms
  - Monitor entire sky for near real-time alerts to multi-wavelength observers of transient outbursts
- GLAST will detect approximately 300 gamma ray bursts per year
  - approx. half positioned to 10 arcmin
  - energy extent and high energy cutoffs from $\gamma\gamma$ pair production - high quality spectra to 100 GeV for about 25 bursts/year
  - new class of GRB - clean fireballs
- Pulsars
  - Polar Cap vs Outer Gap Models
- EGRET Unidentified Sources
- Dark Matter
  - WIMP annihilation, most plausible energy range 30 GeV - 300 GeV
  - GLAST will have good energy resolution out to 100 GeV for side entering photons. GLAST is working to a goal of 2% energy resolution.

Comparison of CGRO/EGRET and GLAST

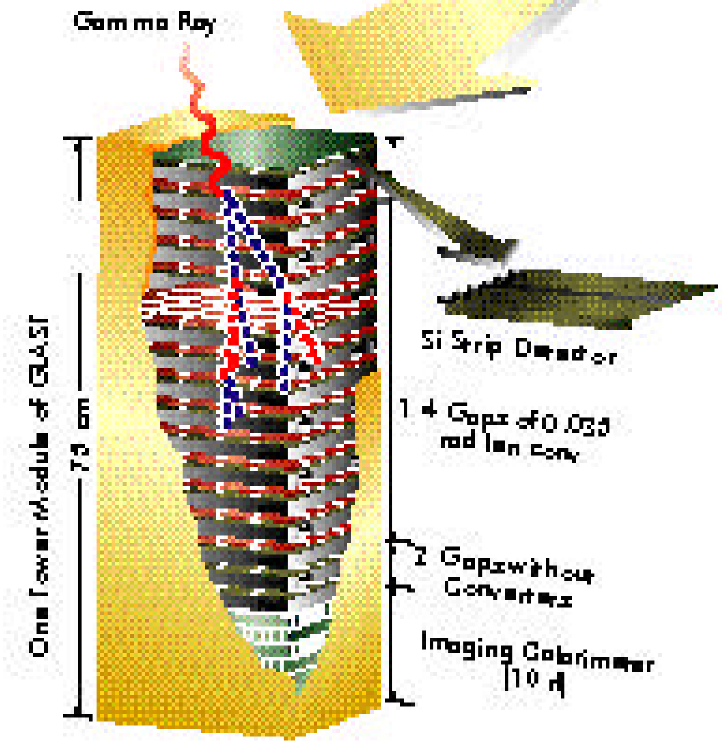
Quantity	*EGRET*	*GLAST*
Energy Range	20 MeV - 30 GeV	20 MeV - 300 GeV
Energy Resolution	20%	10% E >100 MeV
Effective Area	1500 cm^2	8000 cm^2
Single Photon Angular Resolution - 68%	5.8 deg (100 MeV)	< 3.5 deg (100 MeV) < 0.15 deg (E > 10 GeV)
Field of View	0.5 sr	2 sr
Source Location Determination	5 - 30 arcmin	30 arcsec - 5 arcmin
Point Source Sensitivity (> 100 MeV)	~1x 10^{-7} cm^{-2} s^{-1}	4 x 10^{-9} cm^{-2} s^{-1}
Time Resolution	0.1 ms	10 μsec absolute
Background Rejection	> 10^6:1	> 10^5:1
Mission Life	5 years	5 – 10 years
Telemetry Downlink - Orbit average	~6 kbps	300 kbps 1 kbps near-realtime

GLAST Baseline Instrument Concept

GLAST Spacecraft and Instrument



(5 x 5 array of modules, fastened to support grid)



Instrument Module

<u>Instrument is modular</u>. Each module contains elements of the complete telescope:

- **<u>tracker</u>** (TKR): single-sided silicon-strip detectors & converters, arranged in 16 *x*,*y* tracking planes;
- **<u>calorimeter</u>** (CAL): segmented, hodoscopic array of CsI(Tl) crystals, 10. r.l. thick; readout with PIN photodiodes;
- **<u>data acquisition system</u>** (DAQ): 25 identical boards in 4-way redundant network. Parallel serial readouts with FIFO buffers;
- **<u>anticoincidence shield</u>** (ACD): mosaic of plastic scintillator tiles covering front and sides of array.

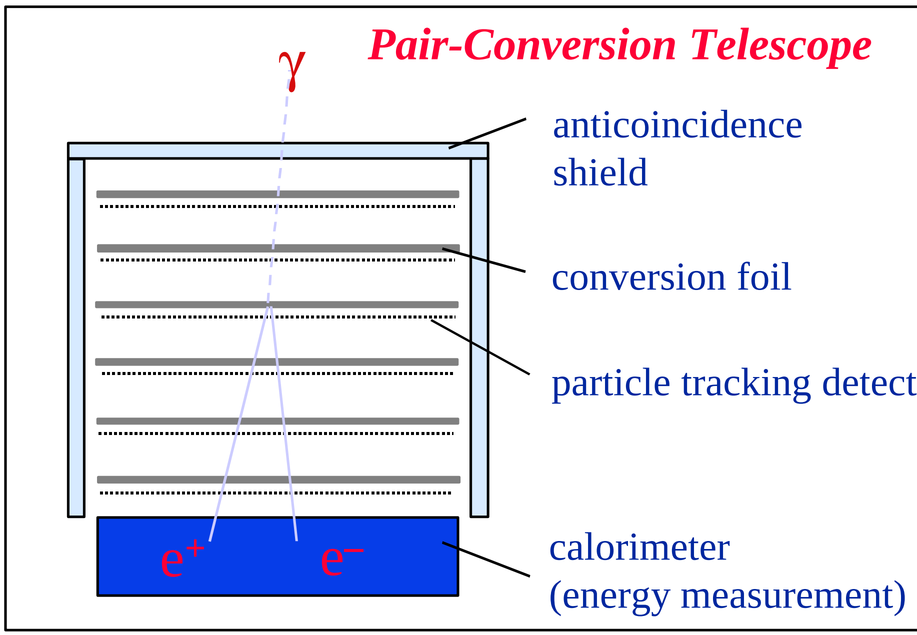
Instrument Requirements

Instrument must measure the <u>direction</u>, <u>energy</u>, and <u>arrival</u> <u>time</u> of high energy photons

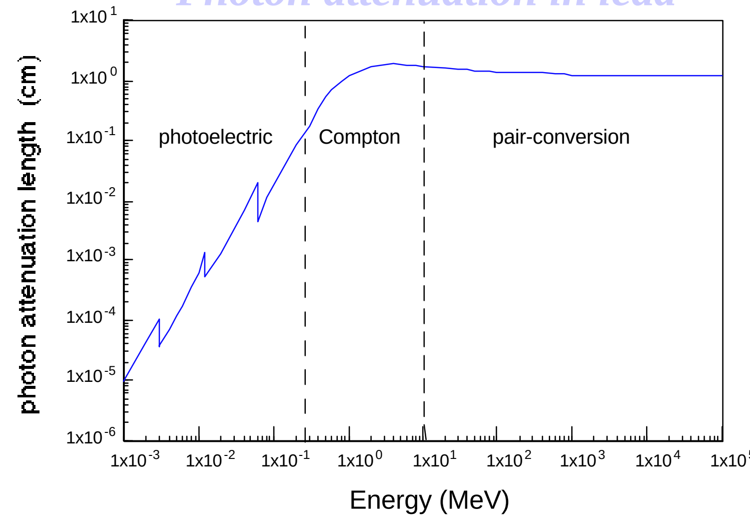
- photon interactions with matter in GLAST energy range dominated by pair conversion:

γ Ü $e^{+} + e^{-}$

- electron and positron carry information about the direction, energy (and polarization) of the incident γ-ray photon

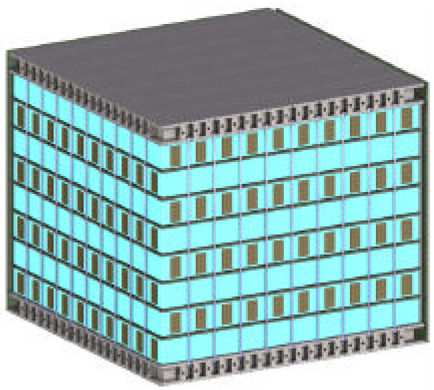


Photon attenuation in lead



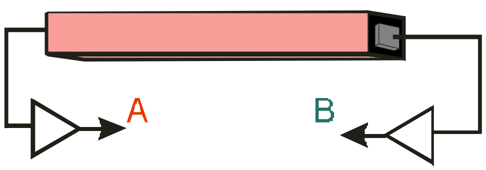
- instrument must detect γ-rays with high efficiency and reject the much higher flux (x 10^4) of background cosmic-rays, etc.
- energy resolution requires calorimeter of sufficient depth to measure buildup of the EM shower

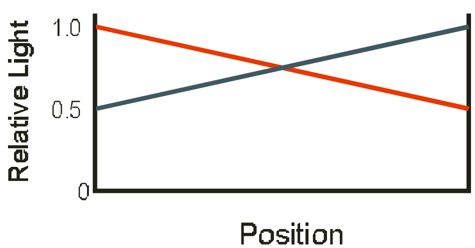
Modular CsI Calorimeter
(PCBs and side walls removed)



Position Measurement

2.3 x 3 x 31 cm





$$\text{Position} = 0.5 + \frac{f^* (A - B)}{(A + B)}$$

- Calorimeter Concept
  - Modular Design integral to GLAST Tower Concept
  - Hodoscopic Imaging of EM Showers
  - CsI(Tl) Detectors with long space history
  - PIN photodiode readout rather than PMTs for reliability and compact design
- Hodoscopic Design
  - 8 layers of 10 CsI blocks
  - 2.3 x 3.0 x 31.0 cm CsI blocks (e.g., 10 r.l. thick)
  - Custom dual-PIN photodiode on each end
  - low-power front end electronics supporting large dynamic range (~10^6)

Mass:	88.4 kg/tower (nom.)
Power:	4.9 Watts/tower (nom.)
Energy Range:	2 MeV - 100 GeV (per CsI block)

Imaging in the Calorimeter provides a significant improvement in the GLAST high energy performance

Performance Enhancement

- Improve background rejection with better discrimination on hadronic showers.
- Improve energy measurement and extend energy range via shower profile analysis.

Science Enhancements

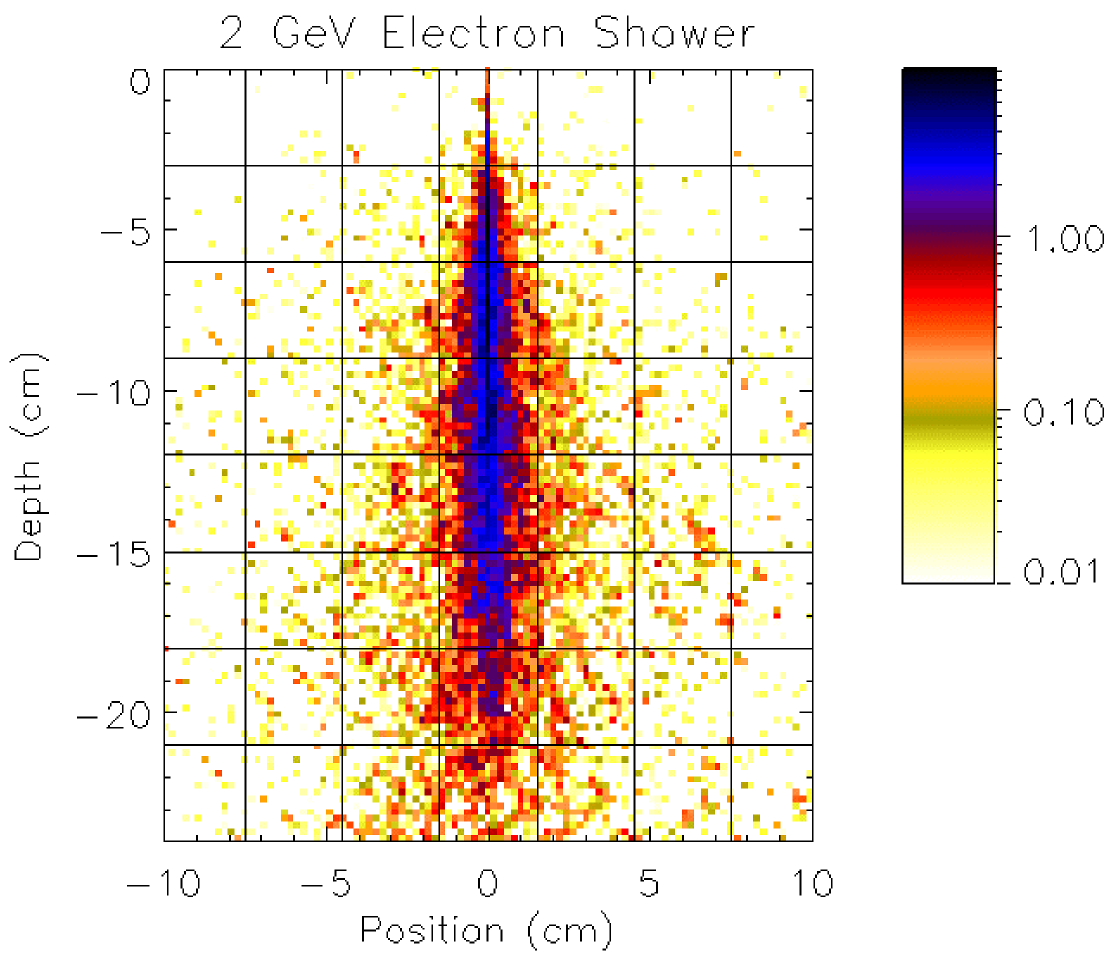
- Improve high energy sensitivity by capturing and imaging those photons which do not convert in the Si Tracker. Only 1/3 of photons > 1 GeV convert in tracker.

Science Return

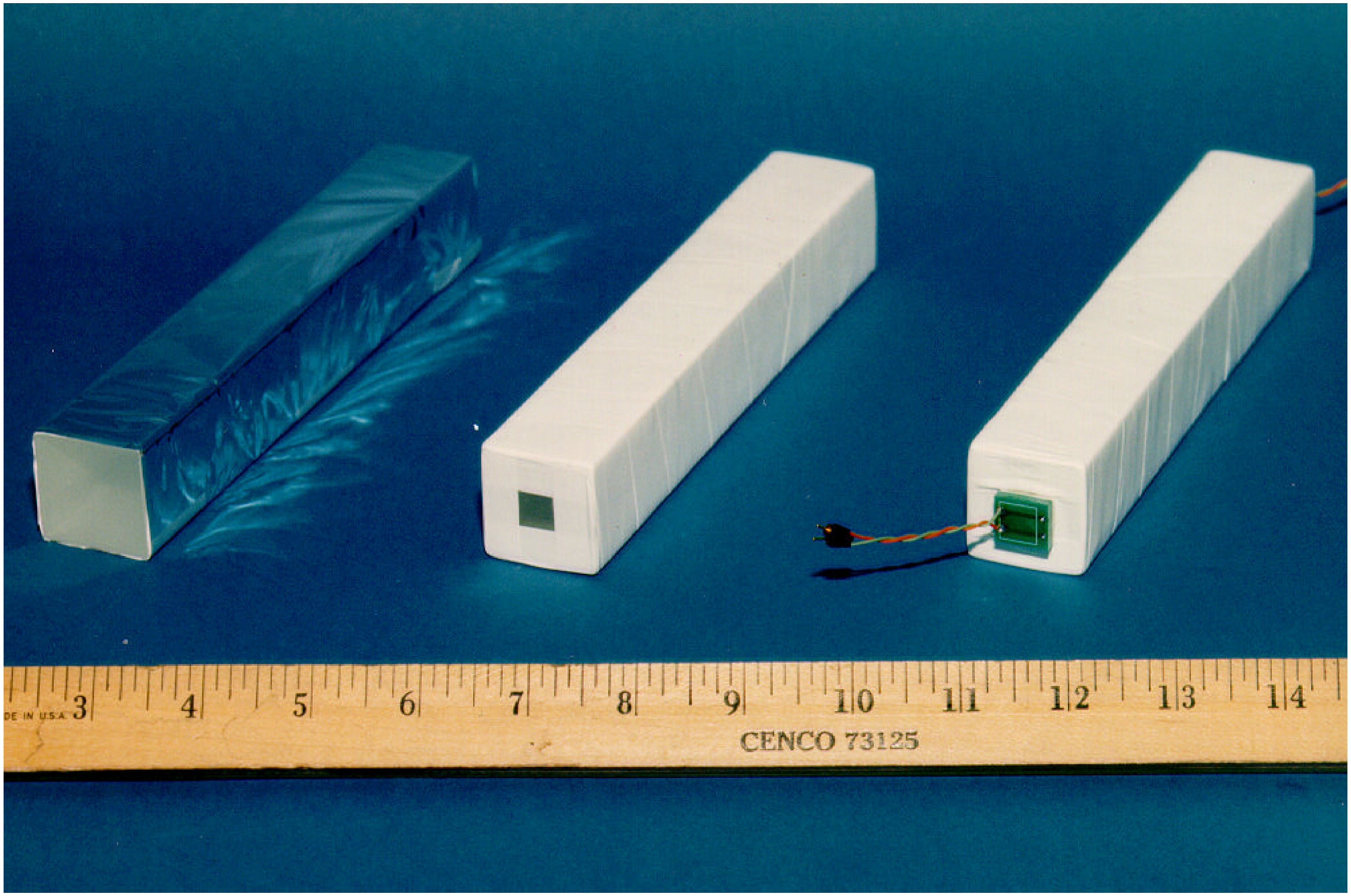
- Spectroscopy on bright sources - spectral cutoffs or breaks in bright AGN, pulsar spectroscopy, and gamma ray burst spectroscopy.
- Serendipity - unexplored energy domain at this sensitivity.

Development of Electromagnetic Shower in the GLAST Calorimeter

- Simulation of 2 GeV electron entering calorimeter from the top.
- Grid represents the segmentation of the calorimeter into 3 cm blocks
- Color coding shows the projected total energy deposited in 2 mm voxels in MeV.
- Maximum energy loss rate (shower max) occurs at depth of 10 cm.

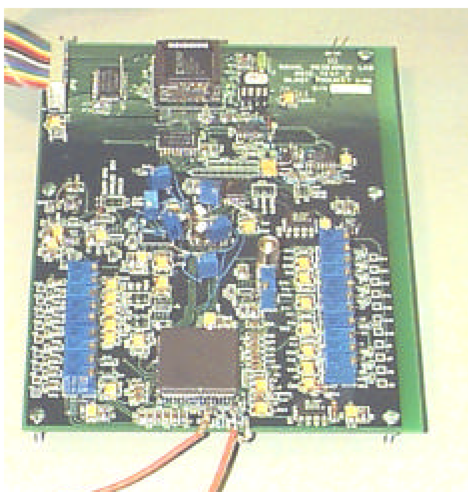


CsI Calorimeter Elements

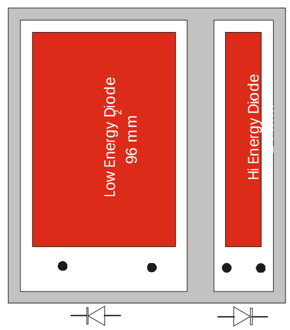


Number of Channels:	320 / tower (80 CsI blocks, both ends)
Dynamic Range:	5×10^5
Noise goal:	0.2 MeV (10^3 e^-)
A to D Range:	1 MeV – 100 GeV
Power:	5 watts / tower
	~ 31 mW / channel

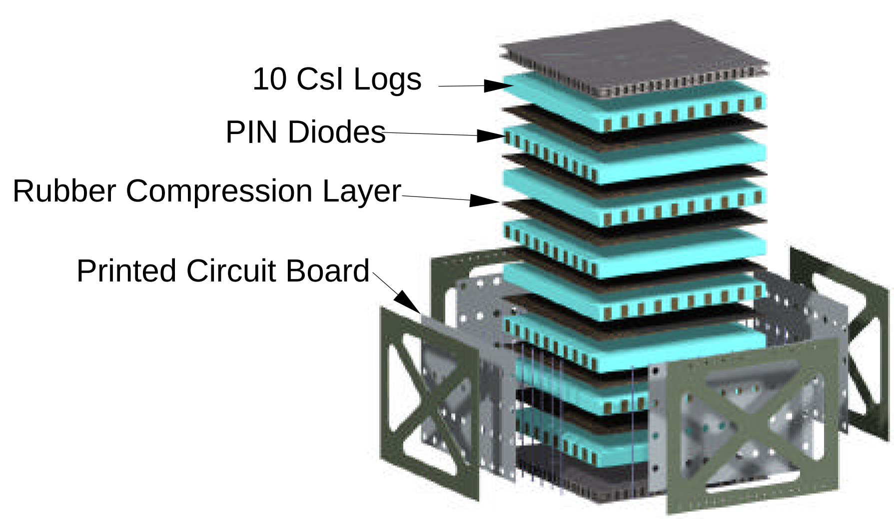
Achieve dynamic range, noise and power performance with dual PIN photodiodes and custom low-power application specific integrated circuit (ASIC) with multiple energy ranges.

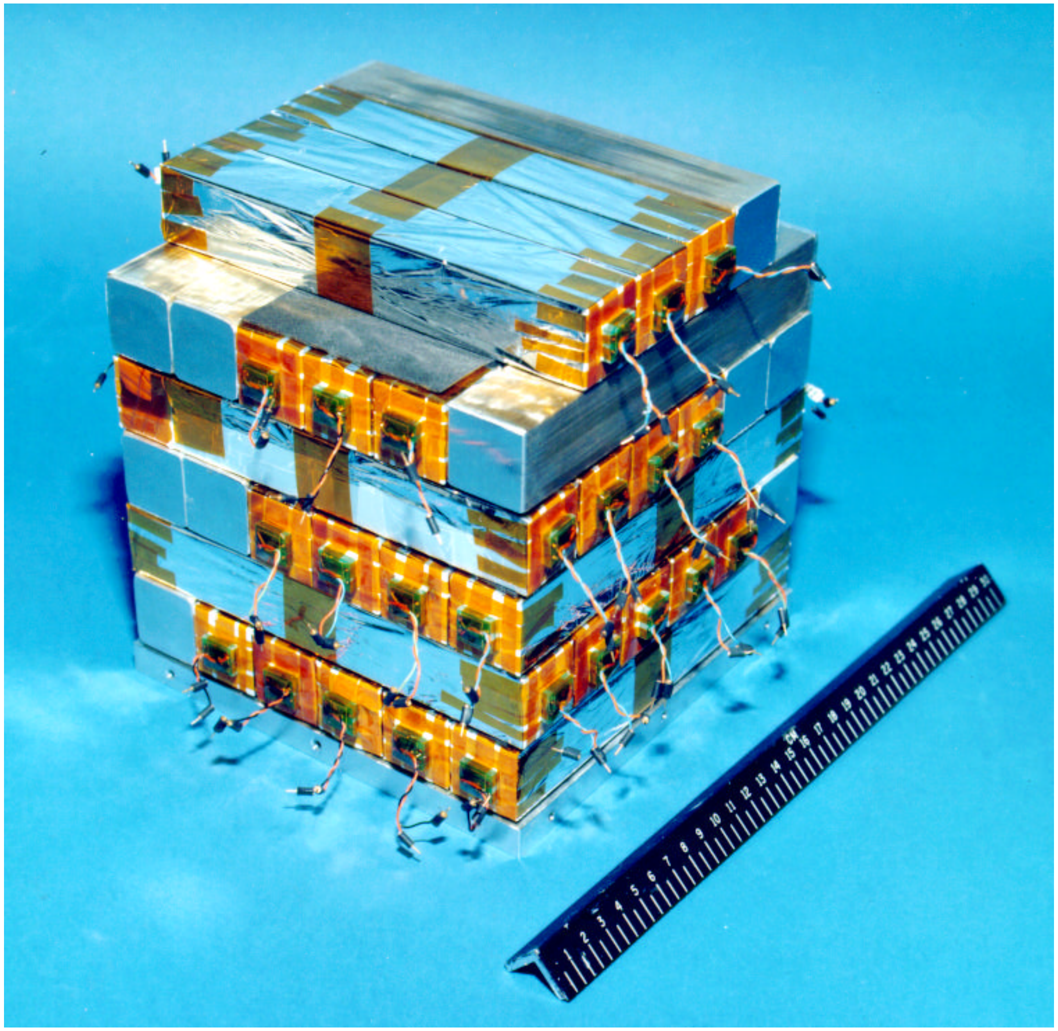


ASIC Development - prototype test board



Custom Dual PIN photodiode



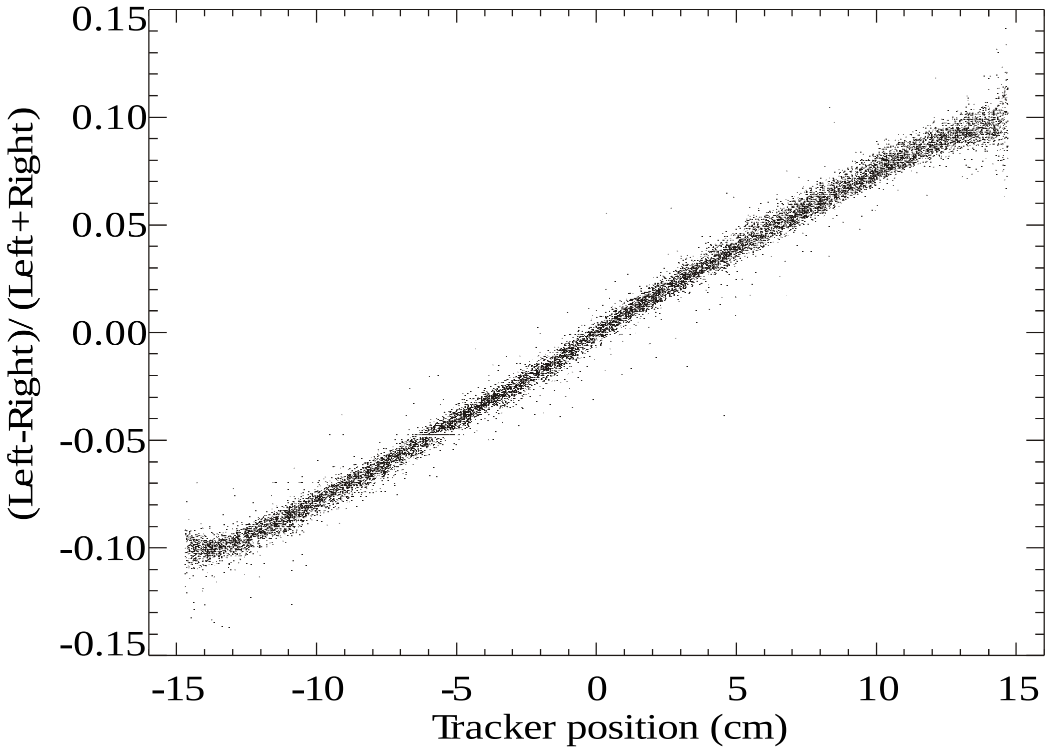


Calorimeter Prototype (partial Stack)
3 x 3 x 19 cm blocks

Also tested single
2.5 x 3 x 32 cm block

32 cm CsI Bar Position Resolution

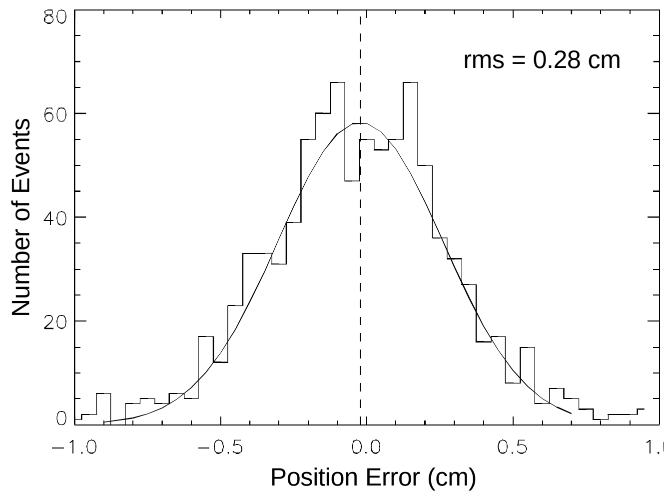
Light Asymmetry



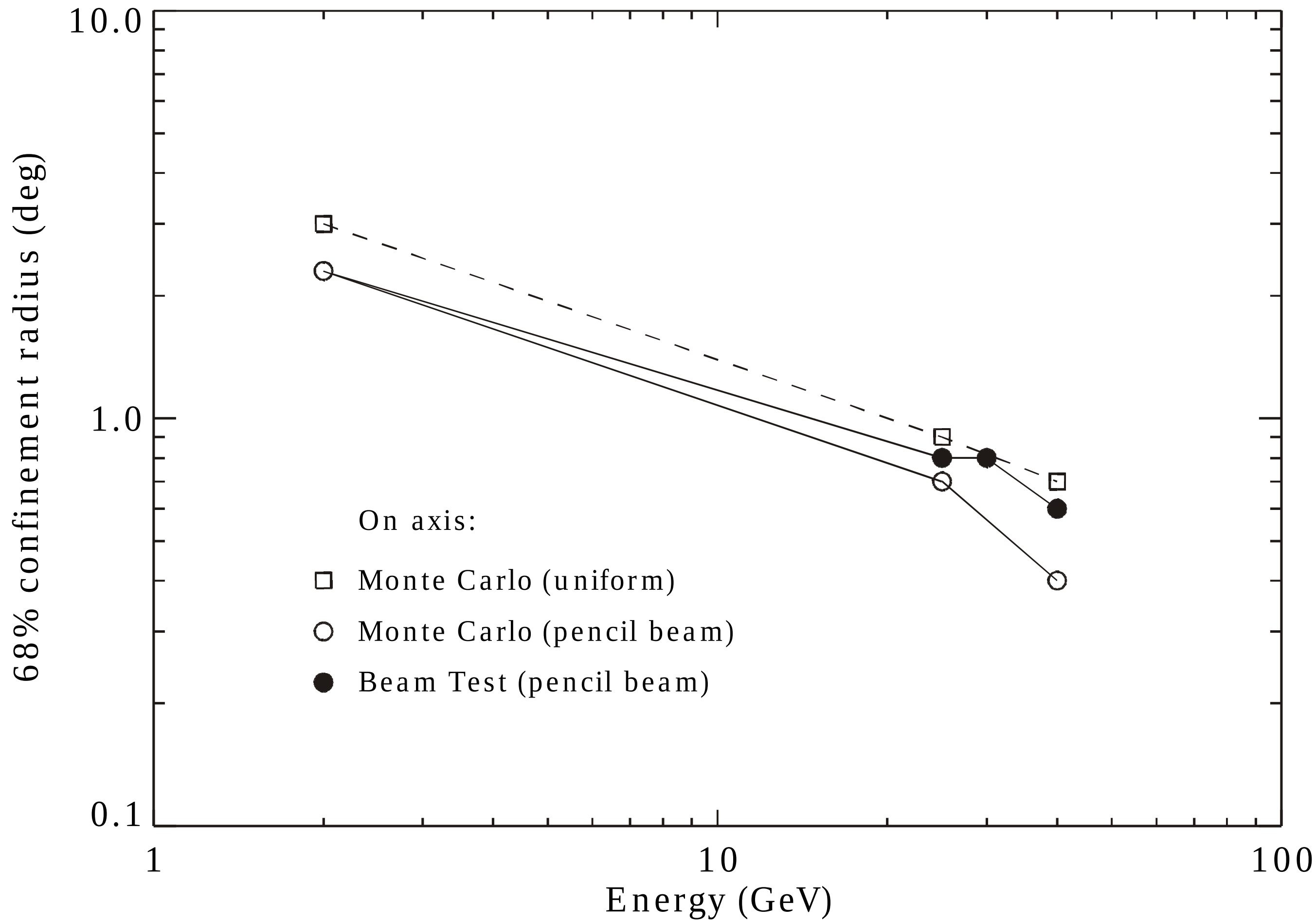
SLAC e^- beam, 2 GeV

$\Delta E \sim 130$ MeV

Position Resolution

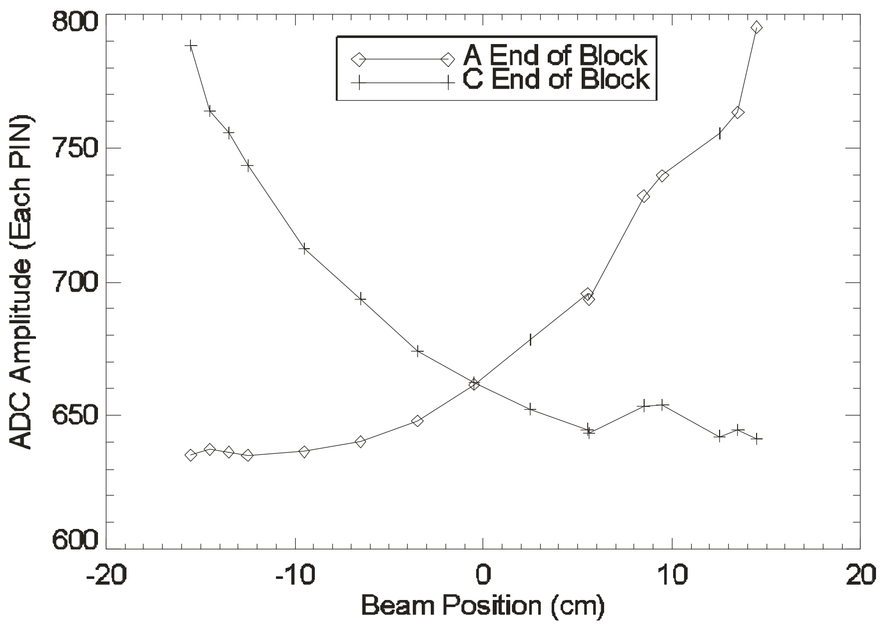


Angular Resolution vs Energy

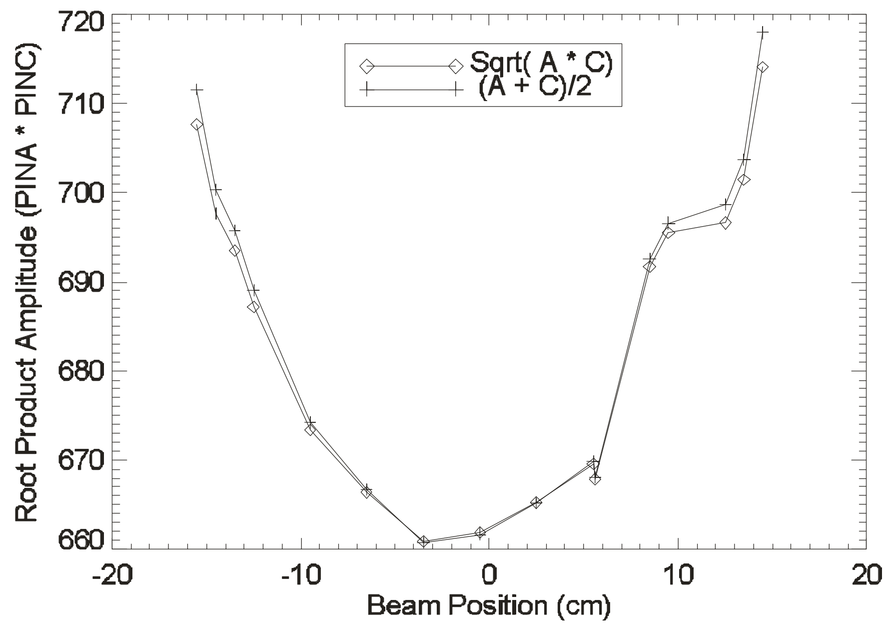


MSU Beam Test '98 - He Beam

Each End of CsI Block



Sum of Ends of CsI Block



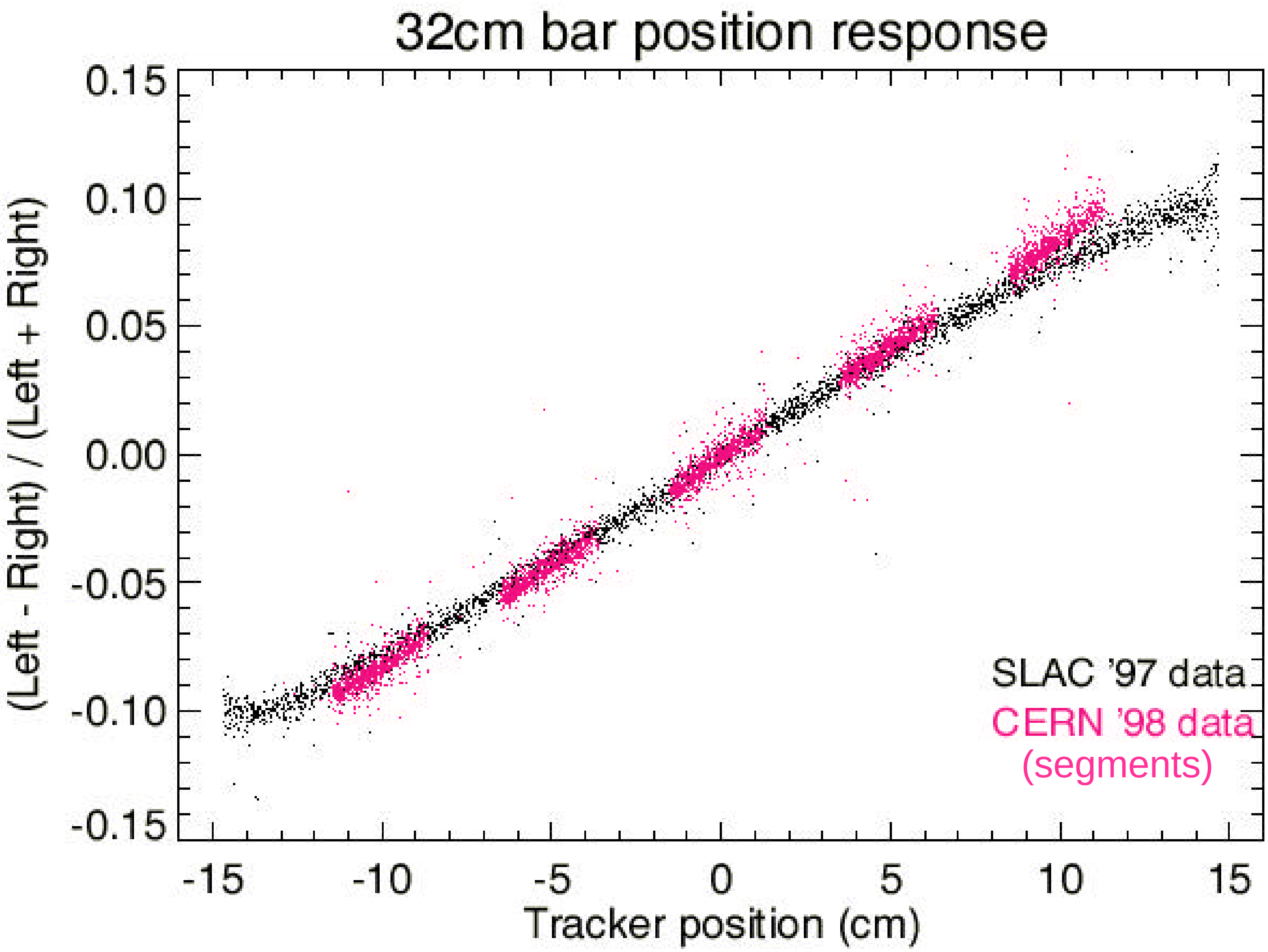
Light amplitude seen at each end of the 32 cm CsI block as a function of position.

He Beam: 160 MeV/nuc
Energy Deposition: ~150 MeV

Sum of signals from both ends of the 32 cm CsI block as a function of position.

Variation with position: ± 4%

CERN Beam Test '98



- **The current GLAST technology development program addresses the following key issues for the GLAST calorimeter:**
  - Optimization of the CsI detector packaging and PIN diode configuration for the imaging science objectives.
  - Development of low-power front end electronics which meet the noise and dynamic range requirements. This includes design and testing of custom ASICs, ADCs, and data acquisition system.
  - Development of mechanical design for the calorimeter compression cell which holds the 80 CsI blocks of a tower module with minimum passive material. Verify that design will protect detectors in expected launch load environment.
  - Identification and evaluation of multiple vendors

- **The prototype calorimeter which is under development for the 1999 beam test will permit evaluation of all of these key technology areas. Previous beam test results indicate that the concepts are sound.**

GLAST Mission Status

- Active Mission Study supported by NASA Headquarters Facilities Science Team
- NASA Scientific Research and Technology Funding development at $1M/yr (NRL portion: ~$200K/yr)
- DOE support through SLAC
- NASA Advanced Technology Development (ATD) Funding awarded at ~$5M/yr. (FY ‘98, $3M) Two instrument concepts under study.
- ATD program developing a prototype GLAST tower for beam testing at SLAC in Fall, 1999
- NASA AO for GLAST mission released Apr, 1999
- ATD review and technology selection in Jan, 2000
- Mission New Start in 2002
- Launch in 2005